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Nondestructive Evaluation & Radar Imaging using Terahertz Signals

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Abstract

Nondestructive imaging is a method of examining a material without direct contact that additionally does not alter the properties of the material. The terahertz imaging system currently in development uses the principle of interferometry (a Michelson Interferometer) such that frequency modulated terahertz signals are split and directed to the object under study and a reference mirror; then the detector will acquire the intensity of the combined reflected signals that contains information about the objects in the path of the beam.

Goals

- To measure object distances with high precision.
- Determine small separations between several objects.
- Create 3D imaging of samples to reveal structural properties.

Theory

Michelson interferometer

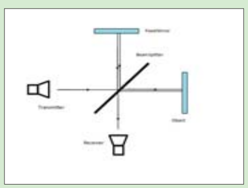

Figure 1. Schematic diagram of the Michelson Interferometer.

- A single wave splits into two at the beam splitter.
- Two waves travel different distances and interfere at detector.
- Constructive or destructive interference occur based on the path difference.

Frequency Modulated Continuous Wave (FMCW)

- FMCW is a radar system capable of determining distances of objects along with speed measurements.
- A continuous signal of a known frequency varies linearly in frequency over a fixed period of time by a modulating signal.
- Frequency difference between the received and the transmitted signal increases with distance which provides a method of determining distances.
- Distance is measured based on the range bin of the signal.

$$Range\ Bin\ (Resolution) = \frac{speed\ of\ light}{2\ \times Bandwidth}$$

Distance measurements

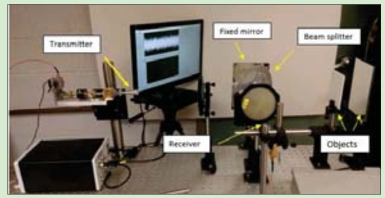

Figure 2. Photo of the Michelson Interferometer.

System configurations
(Frequency Multiplication system)

- Bandwidth: 100 MHz x 12 = 1.2 GHz
- Modulation frequency: 100 Hz
- Carrier Frequency: 9.5 GHz x 12
- Range bin = 6.25 cm

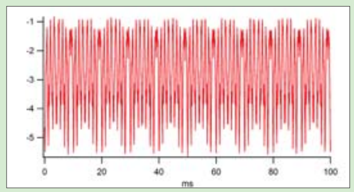

Figure 3. Received signal.

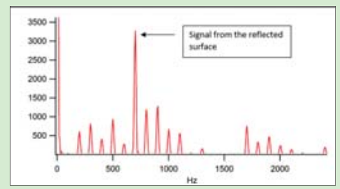

Figure 4. FFT of the received signal.

Experimental Validation:

- Object distance = 24 cm
- Experimentally measured distance= 21.9 cm (±3.1 cm)

Current Imaging system

- Current system is capable of performing 2 dimensional imaging of samples, but not 3D images.
- The imaging platform consists of two automated tracks that allow the plate to move in the x-y plane.
- While the terahertz signal bombards the plate, the plate moves in the x-y plane so reflection information about the entire plate can be recorded.

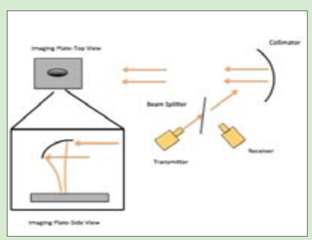

Figure 5. Schematic of Imaging system.

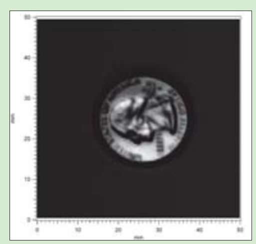

Figure 6. Terahertz image of a quarter.

Current and Future Work

3D Imaging Systems

- Current work is being done to develop two different 3-D imaging systems, one that uses a mirror and another that uses x-y linear stages. Each one could be coupled to the interferometer that provides distance measurements. In combination, they act as a 3-D imaging system.
- This work involves updating the LabVIEW code used to control the mirror or two linear stages. The original LabVIEW program was created to run a two-dimensional raster imaging systems and the FMCW distance/depth dimension needs to be incorporated, which is very data intensive.
- In additional to implementing the x-y (mirror and linear stages) data collection strategies, increasing the bandwidth by a factor of 10 to ~12 GHz will allow the range bin resolution to be ~6 mm.

Movable Mirror and Linear Stages Options

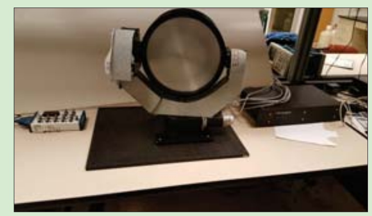

Figure 7. Gimbal mounted, computer controlled mirror.

- In Figure 7 is a gimbal mounted mirror that is able to tilt in the y-direction, and yaw in the x-direction. In this case, the scanning mirror will allow the object to remain stationary and the 2D (x-y) aspects of the 3D image to be created by directing the focused radiation to different positions on the object. The motion of the mirror is controlled by a Newmark controller and a corresponding LabVIEW program to facilitate a raster scanning motion.
- Another method is to move the object by implementing two Anaheim Automation Linear Stages, as shown in Figure 8. In this case, the optics are static and the object is raster scanned using the two linear stages.

Figure 8. X-Y linear stages.